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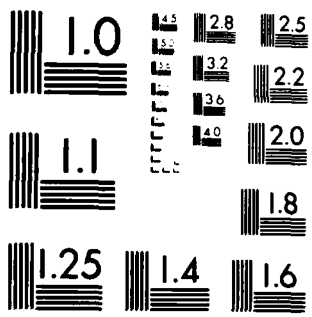

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Previous research has demonstrated that mental imagery is not a unitary, undifferentiated ability, but rather is composed of a set of sub-abilities. A computerized task battery was constructed to assess performance on four imagery abilities, namely: image generation, inspection, maintenance, and transformation. Two patients who suffered left-hemisphere brain damage were tested on this battery and their performance on it was compared to their performance on standard speech/language

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tests. In addition, their performance was compared to that of a control group. The most striking result was the relatively intact imagery abilities, which in some cases were equivalent to those of young, heathy college students. There was also a suggestion that posterior left hemisphere damage may adversely affect some imagery ablities, which is consistent with previous findings.

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Dissociations Between Imagery and Language Processing

Until recently, the common wisdom was that imagery is a right hemisphere activity, and language is primarily a left hemisphere activity (e.g., see Erlichman & Barrett, 1983; Springer & Deutsch, 1981; Kosslyn, Holtzman, Farah & Gazzaniga, 1984). If this notion had held sway, an investigation of possible dissociations between imagery and language ability would have been of questionable interest. But the common wisdom proved incorrect: First, in their review of the neuropsychological literature on imagery, Erlichman & Barrett (1983) discovered that in general imagery is not systematically correlated with either right or left hemisphere processing. Second, in her analytic review of types of imagery deficits, Farah (in press) discovered that there was in fact a strong relationship between damage to one cerebral hemisphere and inability to form mental images (but not inability to engage in other imagery activities, such as image transformation). However, the critical locus was on the _left_ side, not the right! Third, Kosslyn, Holtzman, Farah, & Gazzaniga (1984) found that the _left_ hemisphere of two split-brain patients was _better_ than the right at tasks requiring generation of multi-part images, but not at tasks requiring holding, inspecting, or generating single-part images.

The fact that imagery does not seem to be localized in one place should not be a surprise, given the recent success at decomposing "imagery" into a collection of distinct sub-abilities. Kosslyn, Brunn, Cave & Wallach (in press) showed that people are not simply "good" or "bad" at imagery; rather, they are relatively efficient at performing distinct imagery processes, and these abilities are not highly intercorrelated. For example, one person might be very efficient at retaining images over time, but relatively poor at rotating images, whereas another person might have the reverse proficiences or might be relatively good or bad at both abilities. Similarly, Farah (in press) performed analyses of the abilities used in particular imagery tasks, and showed that these analyses shed light on the relationship between lesions in particular regions of the brain and particular behavioral deficits.

Thus, "imagery" is not a single, undifferentiated ability, and different components of imagery may be localized in different parts of the brain. Indeed, there now is good evidence that the ability to generate an image of a multi-part object from memory invokes left-hemisphere processing; in contrast, the ability to "inspect" or "activate" an image of a single part (i.e., "Gestalt whole") seems to be about the same in both hemispheres. For example, in Kosslyn, Holtman, Farah & Gazzaniga's (1984) experiments, names of animals were lateralized to the left or right visual field, ensuring that they were presented to only the right or left cerebral hemisphere, respectively. In one task, a split-brain patient was asked to decide whether the ears of the named animal did or did not protrude above the top of its skull (as do the ears of a German Shepherd dog, but not the ears of an ape). The left hemisphere was almost perfect in its judgments, whereas the right was at chance. In contrast, when asked to decide whether the named animal was bigger or smaller than a goat, now both hemispheres performed virtually perfectly. In the first task, two parts had to be related correctly; in the second, only the overall shape was necessary, not the arrangements among parts.

The importance of the left-hemisphere in image generation makes sense if descriptions of part relationships (e.g., of the relationship between an animal's ears and its head) are used in generating multi-part images, and such descriptions are manipulated by processes in the left hemisphere (at least in right-handed males). Given the empirical findings and this explanation, it is important to ask whether such processing during imagery is accomplished by processes also used in language.

In this paper we report two case studies of patients with left-hemisphere brain damage. One of these patients is a classic "Broca's aphasic," whereas the other suffers from "Wernicke's aphasia." We examine their proficiency at tasks that depend on specific imagery abilities, and contrast this performance with that on language tasks.

Subjects

Two patients with left-hemisphere brain damage were tested, as were a group of 9 college students. The college students were tested as a baseline, although the disparity in their ages and those of the patients precludes any strict comparison. The brain damaged patients have been extensively tested previously for verbal ability and language skills, providing us with grounds for useful comparison of imagery and verbal/language skills. The patients are described and the results of previous studies of them are summarized in the following sections.

Patient J.E.

J.E. is a college-educated, right-handed male who was 47 years of age in 1983 at the time of his testing. In 1979 he had a series of seizures, followed by mild aphasia and mild right hemiparesis. Arteriography showed a left occipital hematoma, caused by an arteriovenous malformation (AVM). A craniotomy was performed to clip the vessels supplying the AVM and to evacuate the hematoma. A second operation was required some hours later because of marked brain swelling and herniation. At this time, the entire AVM was removed, which necessitated massive resection of the left parietal-occipital lobe. A CT scan obtained in 1981 documents a large area of left hemisphere damage, including the posterior parietal lobe, a portion of the occipital lobe, and the superior posterior temporal lobe.

J.E.'s initial cognitive deficits were severe. He was profoundly aphasic, with neologistic output and poor comprehension. He was completely unable to read or write, and he demonstrated a right homonymous hemianopia. J.E. participated in several lengthy rehabilitation programs, including extensive speech/language therapy and vocational rehabilitation. His current condition is considerably improved, as documented below. He lives with his family in rural Maryland, where he spends much time painting pictures of waterfowl, some of which have been sold commercially.

<u>Patient F.M.</u>

F.M. is a right handed male with high school education who was 40 years old at the time of this testing. In October of 1980 he suffered a left hemisphere cerebrovascular accident, which resulted in a right hemisparesis and moderately non-fluent aphasia. Speech production was very effortful, with reduced rate, dysprosody and severe dysarthria. Language comprehension was moderately impaired. F.M. underwent several months of intensive speech/language therapy, and his condition improved. He currently lives with his family, participates in numerous social activites and lists sailing as his favorite hobby.

College subjects.

The control group consisted of 9 Johns Hopkins University students who volunteered to participate. These subjects were tested in a single session, lasting approximately one and a half hours. The brain damaged subjects were tested in three sessions, each lasting between approximately 45 min and one hour. All subjects were paid for their time, and all subjects were tested individually.

Language Performance: Brain Damaged Patients

The two patients tested here were selected to be subjects for several reasons. Both patients have suffered extensive damage to the left cerebral hemisphere, and both remain moderately aphasic. In addition, both patients have serious impairment of reading and writing abilities. Perhaps most importantly, these patients are highly motivated and cooperative, and their performance tends to be very consistent across test sessions. Despite these similarities, there are important differences between the patients that allow us to investigate possible co-occurences of components of language and imagery processes. First, these patients are representative of the classic distinction between fluent (J.E.) and non-fluent (F.M.) aphasics. Second, F.M.'s reading and writing, although impaired, are clearly superior to J.E.'s. Finally, J.E. suffers from a residual right homonymous hemianopia, while F.M. has never had such a deficit. Thus, these patients display a variety of impairments that may or may not also involve in some way processes relating to mental imagery.

J.E.

Speech comprehension and production

The chronic state to which J.E. has evolved most resembles the syndrome of Wernicke's aphasia, although auditory comprehension is somewhat better than would be seen in the classic case ($z = 0$, relative to a sample described by Goodglass & Kaplan, 1972). Spontaneous speech is fluent and syntactically well-formed, but contains many phonological and semantic paraphasias and frequent word finding pauses. Naming to confrontation ($z = -1$) and to description ($z = -.5$) are markedly impaired, as is repetition of sentences ($z = -1$).

J.E.'s auditory comprehension has been tested in a number of experimental studies, and the results suggest that J.E. has some difficulty with semantic discrimination in lexical comprehension. For example, he produces 100% correct responses in auditory word/picture matching when distractors are unrelated to the target (e.g., windmill/spider), but falls to 70% correct if distractor pictures are semantically related to the target (e.g., truck/bus). Sentence comprehension is clearly impaired when sentences are lengthy and involve complex syntactic structures or low frequency lexical items.

Reading and writing

J.E.'s reading and writing have been the subject of intense study (Berndt, Mitchum, & Coltheart, in preparation). Oral reading is very impaired, with correct responses limited to high frequency concrete nouns. Written word/picture matching is considerably better (76% correct, chance = 50%), unless a two-word, one picture format is used with distractor words visually similar to the target (62% correct). Comprehension of printed abstract words, assessed with a synonym matching task, was at chance. Letter naming is impaired (13/26 correct), with the best performance on letters at extreme points in the alphabet. Letter identification (pointing to a named letter in a five-choice array) was somewhat better (20/26), with errors primarily on letters that are visually similar to the target (e.g., F and P). Cross-case matching to upper and lower case forms is intact.

J.E.'s writing is very impaired, although J.E. is not hemiparetic and therefore can use the preferred hand. Letters are formed neatly and without difficulty, and copying material printed in the same case is intact. Cross-case copying is much slower, with a few errors on letters with clearly different upper and lower case versions (e.g., G/g). Writing to dictation is very poor, with gross spelling errors on even primer level words (e.g., "girl" was written as "hirk"). Examination of these error has revealed a consistent trend for J.E. to substitute letters close to the target in the serial alphabet. Individual letters written to dictation demonstrated the same phenomenon, with intrusions of "neighbor" errors, and performance was poor (12/26).

Compared to this very poor writing performance, J.E.'s ability to spell words aloud is remarkably intact (45% of a 100-word list), with no effect of form class or concreteness. Non-words are spelled as well as words. When errors are committed, they are frequently (49% of all errors) phonologically correct spellings of the target. These occur most often as "regularizations" of words with irregular spellings (e.g., "sign" became "sine"). J.E.'s oral spelling demonstrated all of the characteristics of "phonological spelling" that have been previously demonstrated in the writing performance of some brain damaged patients (Hatfield & Patterson, 1983).

In short, J.E. retains some residual information about the spelling patterns of words, but this information seems to be independent of any retained knowledge of the visual forms of words and letters.

F.M.

Speech comprehension and production

The chronic state to which F.M. has evolved is the classic syndrome of Broca's aphasia. Spontaneous speech is effortful, dysprosodic, and dysarthric, with short utterances and long pauses. Sentence structures are much reduced, with a preponderance of nouns and adjectives. Auditory comprehension on clinical testing is near the mean ($z = +.3$) of a standardization sample of aphasic patients described by Goodglass & Kaplan (1972). Experimental testing demonstrated the "asyntactic" pattern of F.M.'s sentence comprehension. That is, F.M. has great difficulty in comprehending sentences that cannot be understood through lexical-semantic knowledge alone, but require interpretation of grammatical function words and word order. For example, he was only 50% correct on a set of 16 semantically reversible active and passive sentences (e.g., "The boy is hitting the ball"). If a lexical contrast was portrayed in the distractor picture (boy kicking ball) he performed well (92%). For a full discussion of F.M.'s language production and comprehension, see Berndt (in press).

Reading and writing

F.M.'s oral reading conforms to the classic syndrome of deep dyslexia (Coltheart, Patterson, & Marshall, 1980). That is, he is virtually unable to read aloud non-word letter strings (13% correct); he reads concrete nouns (90%) better than abstract nouns (40%) and better than either concrete (60%) or abstract (10%) verbs. He reads grammatical function words very poorly (10%).

About 10% of his reading errors are semantic paralexias (e.g., "rifle" becomes "gun"). Reading comprehension is good for single concrete nouns and verbs (99% for word/picture matching), and synonym matching showed a slight difference between concrete (100%) and abstract words (83%). Written sentence comprehension shows the same pattern as auditory comprehension (i.e., it is good only when lexical information is sufficient for correct understanding).

F.M.'s writing is accomplished with some difficulty, with the non-preferred hand, since he remains hemiparetic on the right. Copying within the same case is slow but accurate. Written naming was moderately impaired (58%) for a 72 item list of regular and irregular words. A large proportion of his errors (60%) were productions of letter strings that are visually similar to the target (e.g., "camel" became "canel"). It appears that F.M. does not generate phonologically-based spelling patterns for a target word, but relies on residual information about its visual form.

The Imagery Tasks

The imagery testing made use of a package of tasks presented on the Apple computer. The Apple Imagery Battery (AIB) was designed to measure four imagery abilities. These abilities are central to performing most "real life" imagery tasks. For example, consider how you decide the best way of arranging many pieces of luggage into a car's trunk. Many people report imaging the suitcases, and mentally rotating them, "trying out" various fits, all the while maintaining images of other bags that seem best placed in specific locations. Such tasks involve:

1) Image maintenance. The image must be retained over time; we assess how

well information can be maintained in an image.

2) Image generation. The image often must be generated from stored information; we assess the ability to use stored information to create a mental image.

3) Image scanning. The image often must be scanned across, as one searches for a part, property, or object; we assess how well a person can shift attention over an image.

4) Image rotation. The object in the image often must be transformed, such as by being rotated, as one examines it from different angles; we also assess how well a person can rotate mental images.

The challenge in designing tests of the individual abilities is to attempt to minimize the importance of all but one of the abilities for performing the task. In addition, we needed tasks that naturally require imagery, and which can be validated to require imagery.

<u>Image maintenance</u>

The method we used to assess a person's ability to maintain material in an image is adapted from a task developed by Podgorny & Shepard (1978). Podgorny & Shepard showed subjects displays like the one presented on the left side of Figure 1. A dot or dots was then presented in the matrix, and the subject's task was to determine whether the dot(s) fell in a cell that was blacked out (i.e., was part of the figure). Response times varied with a number of factors, such as the number of dots and where they fell on the letter (e.g., dots falling on an intersection were faster than dots falling on a limb); times did not depend on the location of dots on the grid itself, however, suggesting that a parallel search (not left-to-right or top-to-bottom) took place.

In another condition of Podgorny & Shepard's study, subjects performed the same task by projecting an image of the letter into the grid, imagining that certain cells were filled. Now subjects decided whether the dots fell in cells "occupied" by the image (as illustrated on the right side of Figure 1). The interesting result was that times varied in exactly the same way in the two conditions: the number of dots, location on the figure, and so on had exactly the same effects when the figure was actually present and when it was only imagined to be present. The imagery condition did require more time in general, but that was the only difference between the two conditions. The striking similarity in response times was exactly as expected if imagery utilizes the same classification processes used in perception, and hence these results are good evidence that imagery was used in performing the task.

We have used a variant of the Podgorny & Shepard task to assess subjects' imagery "memory span." If subjects are asked to generate an image of a named pattern (such as a letter), processing is required to form the image on the basis of information stored in memory. We wanted to eliminate such processing in order to assess image maintenance ability per se. Thus, in this test we show subjects a pattern in the matrix, and let them study it until they have memorized it (at which point they press a button). The computer then removes the filled squares--leaving only the empty grid. Following this, two x marks appear, and the subject must indicate whether or not both x's fell in cells that had been filled by the pattern. Hence, in this task the subject must maintain the image of the pattern until two x's appear. On half the trials, both x's fall in cells formerly occupied by the pattern, and on half of the trials one of the x's falls in a cell formerly empty (and hence presumably not occupied by the image). Subjects press one key if both x's fell on the imaged pattern, or another if both did not.

INSERT FIGURES 1 AND 2 ABOUT HERE

Four versions of this "image maintenance" test are administered in the AIB, which differ in the complexity of the grid (4 x 5 or 5 x 7, with 20% of the cells being filled in both cases), as is illustrated in Figure 2. We varied both the image complexity and the length of time between the removal of the figure and the presentation of the x marks (500 or 5000 msec). Comparison of performance in the different conditions allows us to assess the relative capacity and tenacity of a subject's imagery.

The tasks were administered with the monitor being placed approximately 18 inches from the subject's face; the grids used in this task subtended about 7 degrees of visual angle. In addition to the computer-presented tasks, paper and pencil examples were prepared for instructing the brain-damaged subjects. These materials will be described in the procedure section below.

<u>Procedure</u>

The college students were given written instructions, which they read at their own pace. After reading the instructions these subjects were given eight practice trials in the simple, brief delay condition; feedback was given on each of these trials (subjects were told whether or not they were correct and were prompted with the message "too slow" if they required more than 10 sec to respond).

With the brain damaged subjects, we first verbally described the task and then used pencil and blank 4 x 5 grids to illustrate the nature of the trials. The subject was shown a grid with a pattern penciled in, and then was shown a grid with two x marks, and then the two grids were superimposed in order to explain the nature of the task. These subjects were shown pairs of x marks until they could answer correctly on three trials in a row. These subjects then received the eight practice trials on the computer.

The test trials were like the practice trials except that no feedback was given. Twenty trials were presented in each of the four conditions, with the conditions being presented in the following order: simple, brief delay; simple, long delay; complex, brief delay; complex, long delay. Each set of trials was preceded by eight practice trials of that type, and all subjects were allowed to repeat the practice trials until they felt comfortable with the task. The actual test trials were divided into two blocks of 10 trials, within which there were an equal number of "true" and "false" trials; trials were randomized except that no more than three trials of either type could appear in a row. Each trial used a different stimulus pattern.

Results

Perhaps the most interesting results are revealed when we compare the performance of our brain-damaged subjects with the young, healthy college students. In order to analyze the data from the control group along with the two patients in this and all subseqent tasks, we created a single "normal subject" from the control group by averaging the data for each trial, pooling over subjects. We analyzed the errors and the response times in two separate analyses. The error rate data are the most interesting, given that the differences in procedure and responses described above make it difficult to interpret the response times. Figure 3 illustrates the error rate results. First, all subjects responded with the same degree of accuracy, $F < 1$. Subject J.E. commited errors on 16.9% of the trials, F.M. on 14.4% of the trials, and the controls on 13.5% of the trials. Left hemisphere damage clearly did not disrupt the general ability to maintain images. Indeed, there was no interaction between subjects and complexity, $F(2, 128) = 2.00$, $p > .14$; subjects and response type, $F(2, 128) = 2.09$, $p > .12$; or any of the higher-order interactions with subject, $p > .17$ in all cases. The only effect of subject was an interaction between subject and delay, $F(2, 128) = 3.73$, $p < .03$. This interaction was somewhat puzzling: For the short delay, error rates were 17.5%, 7.5%, and 14.0% for J.E., F.M., and the control group, respectively. Patient F.M. did better than the others. For the long delay, however, the error rates were 16.2%, 21.2%, an 12.9% for J.E., F.M., and the control group; now F.M. is the worst of the lot!

The lack of significant differences among the subjects is not due to inherently noisy data. This conclusion is demonstrated by a host of significant effects and interactions that were revealed by the analysis: More errors were made for complex patterns than simple ones (25.6% versus 4.2%), $F(1, 64) = 77.58$, $p < .0001$; for complex patterns with a long delay but for simple patterns with a short delay (21.3% versus 29.9% for complex patterns at short and long delays, and 4.7% versus 3.7% for simple patterns at short and long delays), $F(1, 64) = 3.92$, $p < .06$; for complex "true" patterns than complex "false" ones, but vice versa for simple patterns (31.2% versus 20.0%

for complex "true" versus "false" probes, and 2.7% versus 5.7% for simple "true" and "false" probes); for "false" probes than "true" probes at short delays, but vice versa for long delays (8.8% versus 17.2% for "true" and "false" probes at short delays, and 25% versus 8.6% for "true" versus "false" probes at long delays), $F(1, 64) = 25.9$, $p < .0001$; and there was an interaction between complexity, delay, and response type, $F(1, 64) = 11.45$, $p < .002$, with the "true" probes displaying larger effects of complexity with the long delay, whereas the "false" probes displaying larger effects of complexity with the short delay. There was also a tendency for the subjects to make more errors with "true" probes in general, $F(1, 64) = 2.99$, $p < .1$, but no other effect or interaction approached significance, $p > .12$ in all cases.

INSERT FIGURES 3 AND 4 HERE

We also analyzed the response times. Not surprisingly, there were overall differences in the speed of responding of the subjects (with means of 3.844, 2.428, and 1.866 sec for J.E., F.M. and the control group, respectively), $F(2, 128) = 134$, $p < .0001$. As noted earlier, the brain damaged patients were not forced to keep both hands on the keyboard, and in fact (because of his hemiparisis) F.M. responded with two fingers of one hand. Thus, this effect is not particularly interesting. Of more interest are several interactions between subjects and other factors. First, as is illustrated in Figure 4, complexity affected the subjects in different ways, $F(2, 128) = 8.16$, $p < .001$, and delay affected the subjects in different ways, $F(2, 128) = 7.31$, $p < .001$. Patient F.M. resembled the control group for the effects of complexity, and J.E. did not, but with regard to the effects of delay the two patients were much more similar to each other than to the control group. Second, there was an interaction between subject, response type, and delay, $F(2, 128) = 3.37$, $p < .05$, with "true" probes requiring more time than "false" ones for all subjects with the long delay, but only for the control subjects with the short delay.

Again, there were a number of additional significant effects and interactions: More time was taken for the more complex displays (2.108 versus 3.317 sec for simple versus complex), $F(1, 64) = 84.4$, $p < .0001$, and for the longer delay (2.410 versus 3.015 sec for the short and long delays), $F(1, 64) = 21.1$, $p < .0001$. In addition, the effects of complexity were more pronounced for longer delays, $F(1, 64) = 8.25$, $p < .006$; the effects of complexity were more pronounced for "true" probes, $F(1, 64) = 5.30$, $p < .05$; and there was a tendency for larger effects of delay for "true" probes, $F(1, 64) = 3.37$, $p = .07$. There was also an uninterpretable five-way interaction between complexity, delay, subject, truth, and block, $F(2, 128) = 3.55$, $p < .04$. No other effects or interactions were significant, $p > .15$ in all cases.

In a second set of analyses we examined data only from the two brain-damaged subjects. For the accuracy data, there was no difference between the subjects, $F < 1$, and the only significant interaction with subject was between delay and subject (as described above), $F(1, 64) = 4.72$, $p < .05$. There was a tendency for J.E. to make equal numbers of errors for "true" and "false" probes (16.2% and 17.5%, respectively) whereas F.M. made more errors on "true" probes (20.0% versus 8.7%), $F(1, 64) = 3.28$, $p < .08$. In addition, there was a tendency for J.E. to make more errors on the first block for the brief delay, but less errors on the first block for the long delay, whereas F.M. made more errors on the second block for the brief delay but less errors on the first block for the long delay, $F(1, 64) = 3.28$, $p < .08$. For the response time data, J.E. was slower than F.M., $F(1, 64) = 97$, $p < .0001$, and there was an interaction beween complexity and subject (as described above), $F(1, 64) = 7.56$, $p < .01$. In addition, both subjects tended to take longer for "true" probes for the long delay, and longer for the "false" probes for the brief delay, with the exception that J.E. took longer for "true" probes for the second half of the brief delay trials, as reflected in a marginal interaction between subject, delay, truth, and block, $F(1, 64) = 3.34$, $p < .08$. Finally, there was a complex, uninterpretable interaction between subject, complexity, delay, truth, and block, $F(1, 64) = 5.0$, $p < .03$. No other interactions with subject were significant in these analyses, $p > .23$.

Discussion

Probably the most interesting result of this part of the study is the very accurate performance of the two brain-damaged subjects. Their level of accuracy matched that of our control group--even though this group was composed of healthy college students, instead of age and education-matched controls! The response times of the brain-damaged subjects were relatively slower than those of the controls for more complex displays and for displays that had to be maintained longer. These results are interesting but are somewhat difficult to interpret; both of our patients were aware of their deficits, and may simply have been more cautious when responding to the patently more difficult stimuli. Indeed, when watching them perform, the brain-damaged patients would often make an initial move towards responding, and then hesitate before actually committing themselves to a decision.

These findings, then, are in sharp contrast to both the speech production and comprehension deficits and the reading and writing deficits noted above. Apparently image maintenance draws on mental machinery that is realized in different brain tissue than that which underlies at least some of the components of these other abilities.

Image generation

According to the theory of imagery described in Kosslyn (1980), three processing modules are used in generating an image from information stored in long-term memory. The PICTURE processing module simply activates the stored information, forming an image in short-term memory. However, this processing module only activates one "packet" of information at a time. The PUT processing module is used when multiple images are arranged into a single composite (either an image of a single object with details or an image of a scene). The hypothesis is that positions of parts are stored relative to other parts (e.g., a chimney is "on top of" a roof). Thus, the PUT processing module works by using another module, called the FIND processing module, to locate a part in the image (e.g., the roof), and then uses this information to correctly position a to-be-aligned part (e.g., a chimney). The actual positioning of the new image is accomplished by calibrating the PICTURE processing module correctly, and using it to activate the new part in a given position in the image. Thus, all three processing modules are involved when a multi-part image is constructed. Rather than pull apart the two image generation processing modules, PUT and PICTURE--which are always used if a complex image is formed--we designed a test to measure how well they work together.

Our measure of image generation ability involves comparing performance on two tasks. One of our tasks is very similar to the perception condition in Podgorny & Shepard's experiment. Subjects see a pattern in a 4 x 5 grid, two x marks appear in the grid, and the subject decides whether both fall on the figure. If both x's are on the figure, the subject presses one key; if not, he or she presses another. The grid was the same size on the screen as the ones used in the previous task. The computer recorded the responses and response times. These data are useful primarily as a baseline for the imagery tasks. That is, these times include the time to encode the x's, to compare them to the representation (perceptual, in this case) of the figure, to reach a decision, and to respond. Thus, by subtracting these "perceptual baseline" times from the imagery task described below, we derive a better estimate of the speed of the imagery components per se.

The imagery test is similar to the original Podgorny & Shepard task. Now a pattern is not presented in the grid; instead, the lower case version of the letter appears below the grid (which does not physically resemble the upper case version--such as <u>f</u> and <u>e</u>), and two x's appear 300 msec after the letter cue (see Figure 5). The subject's task is to decide whether both x's would have fallen on the letter if it had been in the grid; the subjects are familiarized with the appearance of the letters in the grid before the experiment begins. Three hundred msec is just enough time to recognize the cue and move one's eyes up to the grid, but not enough time to form the image. The logic here is that if the image is not fully formed when the x's are presented, additional time will be required to finish generating it before the comparison phase can begin. Thus, by comparing the times in this condition to the baseline perceptual condition, we derive a relative estimate of how quickly the image was generated. Previous research has demonstrated that this task requires forming an image to perform and has validated this derived estimate of image generation time (Kosslyn & Provost, 1984).

INSERT FIGURE 5 ABOUT HERE

Procedure

The subjects first participated in the imagery condition (we feared that prior exposure to the perceptual baseline condition might give them an opportunity to learn the probe locations or to develop special strategies). The college students were given self-paced written instructions and eight practice trials, as in the previous task. Before participating in the imagery condition, however, the subjects were shown the ten letter patterns used in the task, as they appeared in the grid. Each display included the lower case cue beneath the grid, exactly as it appeared in the actual test trials. Subjects were allowed to review the patterns or the practice trials as many times as necessary in order to feel comfortable with the task. As usual, the practice trials included feedback on accuracy and time, but the test trials did not. A total of 40 test trials were administered, half being "true" and half "false;" each letter occured an equal number of times, appeared equally often with each type of response, no letter was presented twice in a row, and no more than three "true" or three "false" trials appeared in a row. The trials were divided into two blocks of 20 trials, with all factors equated in the two blocks.

We realized that our brain-damaged subjects would be working at a disadvantage because of the difficulties they had in reading letters. Thus, we decided to simplify the task and presented these subjects with only four "patterns" to learn, the letters J, G, H, and L. To avoid confusion during these sessions we referred to the stimuli only as patterns, not as letters. The trick here was first to teach the subjects to remember the patterns, and then to associate each pattern with an--to them--arbitrary symbol, either "j", "g", "h" or "l". This training was accomplished by first showing the four patterns to a subject and allowing him to study them as long as he wished. The subject was then asked to reproduce each pattern from memory by filling in the appropriate boxes on blank xeroxed copies of the grid. The "arbitrary" associations were then demonstrated, and the subject was tested by presenting him with a series of blank grids, each with one of the four lower case stimuli presented below the grid. The subject was asked to draw the corresponding pattern in the grid (i.e., the upper case letter). The subject was corrected when he made an error, and training proceded until the subject could draw all figures correctly twice in a row. This training procedure required about 20 minutes to accomplish.

Following the pattern-learning procedure, the brain damaged subjects were told that they were to perform the probe judgment task only when the stimulus cue was the "j" or the "h"; if cued by a "g" or "l", the subject was simply to press the space bar to continue. This last manipulation was included so that we might receive an indication of how well the subjects could discriminate among the letter cues; good performance on the null response trials would demonstrate at least a rudimentary ability to discriminate the cues from each other. Indeed, neither subject committed more than one error on these trials (i.e., by failing to press the space bar).

Before commencing with the task proper, both brain damaged subjects were tested on their abilities to distinguish between response and no response trials; to distinguish between the patterns associated with "j" and "h", to draw those patterns when given the cues, and to make correct "true" or "false" responses when x's were placed in various cells in the grids. Training for the judgment task involved paper-and-pencil overlays and examples like those used in the image maintenance task described above. In all, about 35 min of training preceded the actual task.

After this training was completed, the brain damaged subjects saw the computer-generated displays for the four letters and participated in eight practice trials on the computer; they were allowed to repeat the practice trials until they felt comfortable with the task. Forty test trials were presented, with the constraints that no letter could appear twice in a row, no more than three or four "true" or "false" trials could appear in a row, and that each letter had to appear equally often with both types of probes.

Following the imagery trials, all subjects participated in the perceptual baseline task. Now subjects were told to indicate whether both x marks fell on the figure or not. The task was explained to the brain damaged subjects using paper and pencil. As usual, eight practice trials (with feedback) preceded the actual test trials, and subjects could repeat the practice trials if they so desired. Forty test trials were administered, without feedback. Each letter occurred an equal number of times, and equally often with "true" and "false" probes; the same letters, in the same order, were used here as were used in the imagery condition given to the control subjects.

<u>Results</u>

<u>Imagery task.</u> We began by analyzing data from the imagery task; for purposes of comparing data from the control and the brain damaged subjects, only responses from the "j" and "h" probes were considered. The only result in the analysis of the accuracy data that even approached significance was the interaction between subjects and block, $F(2, 16) = 3.27$, $p < .07$, reflecting a complete lack of practice effects for the brain damaged subjects and a slight decrement on the second block for the normal subjects. The normal control subjects had an error rate of 8.8%, compared to 10.0% for J.E. and 0% for F.M. Given the differences in the procedure between the brain damaged and normal subjects, this comparison is only interesting because of the relatively good performance of both patients. No other effects or interactions approached significance, $p > .1$ in all cases.

The analysis of the response times revealed a significant difference between subjects, $F(2, 16) = 42.7$, $p < .001$, with the normal control subjects having a mean response time of 1.433 sec, compared to 4.300 sec for J.E. and 4.446 sec for F.M. This result suggests the possiblity of a "speed/accuracy tradeoff", with F.M. being more cautious and hence slower but more accurate. In addition, "true" responses were faster than "false" ones (3.025 versus 3.761 sec), $F(1, 8) = 5.92$, $p < .05$. No other effect or interaction was significant, $p > .1$ in all cases.

More detailed analyses were performed examining only the data from the two brain damaged subjects. The analysis of the accuracy data revealed that there were no significant comparisons of error rates, either within or between subjects, $p > .25$ in all cases. Similarly, the analysis of the two brain damaged subjects' response times indicated only that "true" responses were faster than "false" ones, $F(1, 8) = 6.43$, $p < .05$; no other effects or interactions approached significance, $p > .14$ in all cases.

Perceptual baseline. The results from the perceptual baseline task revealed that all subjects performed remarkably well, with error rates of 2.5, 0, and 3.0% for J.E., F.M., and the control group, respectively. There were no significant comparisions in this analysis, $p > .1$ in all cases. In contrast, the analysis of the response times indicated that there were differences among the subjects, $F(2, 16) = 289$, $p < .0001$, with means of 936, 1691, and 772 msecs for J.E., F.M., and the control group, respectively. In addition, times were generally faster on the second block of trials (1.208 versus 1.058 sec), $F(1, 8) = 10.30$, $p < .02$. No other main effects or interactions were significant, $p > .25$.

Separate analyses were also performed comparing only the two brain-damaged subjects. The results of the analysis of error rates are easy to summarize: There were no significant differences whatever. This is not surprising given that only one error was committed by either subject. The analysis of the response times indicated that F.M. was much slower than J.E., $F(1, 8) = 338$, $p < .0001$. In addition, times were faster on the second block of trials (1.382 versus 1.245 sec), $F(1, 8) = 5.16$, $p < .06$. No other effects or interactions approached significance, $p > .25$.

Derived imagery measure. We conducted the perceptual task primarily as a baseline to control for encoding, judgment, and response processes. Thus, we computed an estimate of image generation error rate and time by subtracting the baseline error rate and time from the corresponding trial in the imagery task. This difference, then, should more accurately reflect image generation performance per se. The analysis of the error rates revealed that there was no overall difference among the subjects, $F < 1$. However. whereas the brain damaged subjects showed no effect of practice, there was a slight impairment on the second block for the normal subjects, $F(2, 16) = 3.27$, $p = .06$; this effect was more pronounced for "true" responses, $F(2, 16) = 3.50$, $p = .05$; and these interactions were reflected in a general tendency for increased errors on the second block, $F(1, 8) = 3.81$, $p < .09$. There were no significant differences in image generation accuracy, between the two brain damaged subjects, $p > .25$.

The analysis of the response times indicated a difference among the subjects, $F(2, 16) = 29.74$, $p < .001$, with derived times of 3.364, 2.756, and .661 sec for J.E., F.M., and the control subjects, respectively. No other effects or interactions were significant, $p > .2$. When we considered only the two brain-damaged subjects, we did not find a significant difference in overall times, $F(1, 8) = 2.30$, $p > .15$, but did find that "true" responses were faster than "false" ones, $F(1, 8) = 5.75$, $p < .05$; no other effects or interactions were significant, $p > .1$.

Discussion

We found that our brain damaged subjects performed remarkably well on the image generation task, again showing no decrement in overall accuracy relative to the control group. However, the differences in the tasks make a strict comparison of accuracy difficult. Nevertheless, at first blush it would seem that the left-hemisphere damage has not greatly affected any of the processing modules used in image generation. This finding was something of a surprise given the previous findings (noted in the Introduction) implicating left-hemisphere processing in image generation. It is possible, of course, that neither of these patients has damage in the part of the brain used in image generation or that they have had ample time to compensate for the damage. In this context, then, the response times are of particular interest, given that our measure of image generation time was longer for the brain damaged subjects even when we subtracted these times from the perceptual baseline, which will control for more general response time impairments. This finding suggests that there may have been some impairment in performance here afterall.

Image Scanning

This task is like the previous ones in that a grid is shown, now with three cells filled in at random. In this task, however, the grid is shaped something like a square donut, with a hole in the center (see Figure 6). The subject studies the grid until he has memorized the filled cells, and then presses a button. At that point the filled cells are emptied and a cue appears for 20 msec. In this test, the cue is either an "x" or an "o", which falls in a single cell. If the cue is an x, the subject is simply to indicate whether or not that cell was filled. If it is an o, he is to indicate whether the corresponding cell on the opposite side of the donut was filled. "Opposite" means diagonal if the cue falls in a corner cell, otherwise it means directly across, through the middle of the donut. By subtracting the x times from the o times we obtain a measure of the subject's ability to scan across an image. In earlier work on image scanning (see Kosslyn, 1980), it has repeatedly been found that increasingly more time is required to scan increasingly greater distances across an image. The donut was generated as large as possible on the monitor, to prevent subjects from being able to "see" all of it clearly at the same time in the image; thus, it subtended about 35 degrees of visual angle.

INSERT FIGURE 6 ABOUT HERE

Procedure

The college subjects were again given written instructions, and read them at their own pace. Following this, they participated in eight practice trials (four x, four o, with half of each being true and half being false). Feedback was provided on these trials, as in the previous tasks, and subjects were allowed to repeat the practice trials until they felt comfortable with the task. The practice trials were followed by forty test trials, without feedback. The trials were divided into two blocks of twenty trials. Half of the trials within each block were x probes and half were y probes, and half of each probe type were "true" and half were "false". No stimulus pattern was used more than once. No more than three trials in a row had the same probe type or same response type.

The brain damaged subjects first were shown blank grids like those used in the task. Patterns were penciled in, and the two probe types were illustrated. The most difficult aspect of the procedure to explain to these subjects was the difference between x and o trials; paper and pencil trials were used until the subject could make the correct response six times in a row (three x probes, three o probes). Following this, the actual practice trials on the computer were presented and then the forty test trials.

<u>Results</u>

The first result worthy of note is that patient F.M. could not be brought to perform the task. This patient is a severe aphasic who has special difficulty with relational terms, and we could never seem to make the instructions clear to him. Indeed, we spent approximately 1.5 hours (over three separate days) trying to teach him the task, to no avail. If we had been certain that he understood the instructions, this deficit would be a dramatic example of a specific imagery dissociation; unfortunately, we have no assurance that the problem was not simply one of linguistic processing or comprehension.

The accuracy results from patient J.E. and our control subjects were thus analyzed without data from F.M. This analysis revealed no significant effects or interactions whatsoever. The control subjects and J.E. had comparable error rates (20.0% versus 11%, respectively), $F(1, 18) = 1.66$, $p > .20$; there was no effect of probe location, $F < 1$, nor of any interaction, $F < 1$ in all cases.

The comparable analysis of the response time data painted a more complex picture: First, J.E. was slower than the controls (3.279 versus 1.147 sec), $F(1,36) = 213$, $p < .001$. Second, "x" probes were responded to faster than "o" probes (1.879 versus 2.547 sec), $F(1, 36) = 17.1$, $p < .001$, revealing the usual effects of having to scan across an image. Third, there was an effect of practice (2.421 sec for block 1, 2.005 sec for block 2), $F(1, 36) = 6.62$, $p < .02$, but this effect reflected primarily the speed up with practice for J.E. (3.652 for block 1, 2.906 sec for block 2, compared to 1.190 and 1.105 sec for the two blocks for the controls), $F(1, 36) = 5.11$, $p < .05$ for the interaction of subject and block. Finally, there was a tendency for J.E. to scan across the image more slowly than did the controls (for x and o probes, times were 2.811 and 3.747 sec for J.E., compared to .948 and 1.347 sec for the controls), $F(1, 36) = 3.39$, $p < .08$.

Discussion

The results from J.E. were interesting in part because they again showed that he could perform the task as accurately as normal college students. Although this brain damaged patient was generally slower, it is important to note that his scanning times were not significantly slower than those of the controls. This finding is remarkable given the difference in age and physical condition between J.E. and the control subjects. In contrast, we never could bring F.M. to perform the task when the stimuli were physically present in front of him; thus, we have confidence that his deficit in performing this task is not imagery-specific, whatever it may be.

Image Rotation

Finally, our image rotation task is a modified version of one originally reported by Shepard & Metzler (1971). They showed subjects pairs of block-like forms, and asked if the blocks were the same shape irrespective of orientation. They found that response times increased linearly with the angular disparity of the stimuli, suggesting that one was "mentally rotated" into congruence with the other. In the AIB, two-dimensional forms are generated by selecting six cells in a grid at random, with the constraint that they form a single connected shape. The frame and extra cells are eliminated, producing shapes like those illustrated in Figure 7.

INSERT FIGURE 7 ABOUT HERE

In this task, a pair of stimuli are presented side by side, with the left always being upright (i.e., the longest axis is aligned vertically). The right stimulus is presented at one of ten orientations, and half the time is identical to the left one and half the time is a mirror-reversal. Only two-dimensional rotations are allowed in this task, and a "true" trial is defined as one in which one form can be rotated in the picture plane so that it is congruent with the other. At the corresponding tops of both stimuli are asterisks, which minimizes the task of discovering the relative orientations of the figures so that one can know which direction to begin rotation (subjects typically rotate "the short way around"). The two stimuli together subtended about 20 degrees of visual angle.

The variable of most interest here is the amount of the increase in times when stimuli are presented at increasingly disparate orientations. This measure allows us to assess the efficiency of the ROTATION processing module independently of processing modules that maintain an image or compare them, given that these processing modules are used in all conditions (and hence do not contribute more to the times when more rotation is required). Furthermore, the use of asterisks eliminates the possiblity that the effects of amount of rotation simply reflect the added difficulty of locating corresponding portions of the two figures. According to our theory, however, when the ROTATION processing module is used, the FIND processing module must also be used to monitor the image's progress (and stop the ROTATION processing module when the image has been transformed far enough). Thus, the efficiency of mental rotation is in fact a joint function of the efficiency of the two processing modules.

Procedure

The college students read the instructions and participated in eight practice trials, which provided feedback on accuracy and time. As usual, these subjects were allowed to repeat the practice trials if they so desired. Following this, these subjects participated in forty test trials, which did not include feedback; these trials included an equal number of stimuli at ten different relative orientations (at 36 degree intervals), and an equal number of the stimuli at each orientation were "true" and "false." No stimulus pattern was used more than once. The presentation order was randomized, except that the same orientation could not appear twice in a row, and no more than three "true" or "false" trials could appear in a row.

The brain damaged subjects were first shown cut-out figures that could be physically manipulated to illustrate the various orientations used in the test trials. We demonstrated that some figures were identical once one had been rotated into alignment with the other, whereas other figures were different. The task was to decide whether two figures were identical when they were aligned; in the task itself, we explained, the subject would not be able to actually move the patterns, but would have to do so "in his head." We also explained that only rotations in the picture plane were permitted: any movement was allowed so long as the figure remained flat on the table, or "on the screen" in the actual tests; three-dimensional movements (lifting the cut-out off the table or the figure off the screen) were not permitted in this task. We further explained this constraint by showing how a left and a right hand resting flat with palms down could not be rotated into congruence if they remained flat on the table. Once the subject could perform four trials correctly, when allowed actually to move the cut-outs, he was then given the computer-generated practice trials followed by the actual test trials.

Results

The error rates are illustrated in Figure 8. As is evident, not only did the subjects differ in their error rates, with F.M. being more accurate than either J.E. or the control group (with error rates of 10.0%, 2.5%, and 14.4% for J.E., F.M., and the control, respectively), $F(2, 40) = 5.79$, $p < .01$, but there were interactions between subject and response, $F(2, 40) = 6.32$, $p < .005$, and between subject by angle by response, $F(18, 40) = 2.87$, $p < .005$. In addition, errors varied for the different angles, $F(9, 20) = 4.45$, $p < .003$, and there were more errors for "false" pairs than for "true" pairs (12.3 versus 5.6%), $F(1, 20) = 5.44$, $p < .05$. Furthermore, accept for error on "true" trials for the control group, the error rates did not systematically increase with angle. No other effect or interaction was significant, $p > .1$ in all cases.

The analysis of response times also revealed differences among the subjects (with means of 7.931, 8.741, and 2.770 sec for J.E., F.M., and the control group, respectively), $F(2, 40) = 95$, $p < .0001$. As is illustrated in Figure 9, times varied systematically with angle, $F(9, 40) = 6.09$, $p < .001$, replicating the now-familiar hallmark of "mental rotation" originally reported by Shepard and Metzler (1971). However, it would appear as though F.M. sometimes did not rotate "the shortest way around." This notion is consistent with our finding that angle had different effects for different subjects, $F(18, 40) = 1.88$, $p < .05$, but this interaction probably also reflects the fact that the brain damaged subjects rotated much more slowly than did the controls (i.e., their rotation slope is much steeper in Figure 9). More direct support for the reliability of the odd rotation function visible for F.M. for "false" trials comes from the significant interaction between subject, angle, and response type, $F(18, 40) = 2.03$, $p < .05$. In addition, as is evident in Figure 9, "true" responses were generally faster than "false" ones, $F(1, 20) = 13.06$, $p < .002$; response type had different effects for the different subjects, $F(2, 40) = 4.03$, $p < .03$; and the effects of response type were different for the different angles, $F(9, 20) = 2.40$, $p < .05$.

As usual, we examined more closely the accuracy data from only the two brain damaged subjects. This analysis revealed only a marginal difference in overall performance between the two patients, $F(1, 20) = 3.00$, $p = .099$, although response type had different effects for them (J.E. only made errors on "false" trials, whereas F.M. only made errors on "true" trials), $F(1, 20) = 8.33$, $p < .01$, and the two subjects were affected differently by the different response types at different angles, $F(9, 20) = 2.41$, $p < .05$. The only other effect or interaction to approach even marginal significance was a tendency for generally greater errors on "true" trials, $F(1, 20) = 3.00$, $p = .099$. The subjects were not affected differently by different angles, $p > .20$, and no other effects or interactions were significant, $p > .15$ in all cases.

We also performed a separate analysis of only the response times from the two brain damaged subjects. There was no significant difference in the overall times for the two, $F(1, 20) = 1.65$, $p > .2$, and only one interaction involving subjects approached significance: There was evidence that angle affected the subjects differently for the different response types, reflecting

F.M.'s skewed rotation function for "false" trials, $F(9, 20) = 2.24$, $p = .064$. In addition, this analysis revealed significant effects of angle, $F(9, 20) = 4.97$, $p < .002$; response type, $F(1, 20) = 11.14$, $p < .005$; and an interaction between response type and angle, $F(9, 20) = 2.54$, $p < .05$. No other interactions were significant, $p > .15$ in all cases.

INSERT FIGURES 8 AND 9 ABOUT HERE

Discussion.

Although the results leave no question that these patients can perform mental rotation, they revealed that they are dramatically slower than are normal controls. Because we are examining slopes here, and not simply overall times, the measure is less sensitive to the general impairment of the brain damaged subjects. The additional pre-training given to the brain damaged subjects precludes our making close comparisons to the error rates of the controls (as do the control subjects' faster times--which may inflate their errors due to a speed/accuracy tradeoff). But it is remarkable that even in the face of this additional training, left-hemisphere damage appears to slow down the rate of rotation (even if we ignore the 180 degree pairs, in which the controls made an inordinate number of errors, and these times may be faster than they should be due to a speed/accuracy tradeoff). In addition, there is some evidence that left-hemisphere damage may sometimes disrupt the control people normally have over the direction of rotation: F.M.'s response times suggest that he had a tendency (evident for "false" pairs) to rotate in only one direction, even if it were the "long way around," whereas the other subjects appear to have rotated the shortest way around.

General Discussion

To summarize, when we considered error rates, only in one task was there a significant difference in overall accuracy between the patients and the controls--mental rotation, and here F.M. was the most accurate subject. When we considered response time, in contrast, the picture is more complicated because of the response deficits of our brain damaged subjects. We can conclude with impunity, however, that left-hemisphere damage slows down the speed of image generation and the rate of mental rotation. In both of these cases our response measures control for general impairments in encoding, judgment, and response speed (by subtracting baseline times or using slopes). However, our results suggest that left-hemisphere damage may have only marginal effects, if any, on the speed of image scanning. In addition, if we derive a rough estimate of image inspection time by subtracting the perceptual baseline times (obtained in the generation task) from those obtained in the first task, we find that F.M. is actually faster than the controls. Thus, we have good evidence for deficits in processing time for only two of the tasks: image generation and mental rotation.

The suggestion that left hemisphere damage may disrupt image generation is particularly interesting in the context of Kosslyn's (1980) theory of imagery. According to this theory, descriptions of spatial relations are used when any multi-part pattern is imaged. These descriptions indicate how parts are attached to each other, and purportedly are used to arrange images of separate segments into a composite image. Previous work has indicated that letters are formed from separate parts, each corresponding to a "stroke" (see

Kosslyn & Provost, 1984). Thus, it is interesting that there was a response time decrement in our image generation task for the patients, even when we controlled for possible differences in response, encoding, and judgment times. Perhaps descriptions of the relations among parts are either stored or processed primarily in the left hemisphere. This notion makes sense if processing of descriptions is at all language-related; our subjects are clearly language-impaired. Note that even though the subjects have different degrees of reading and spelling deficits, there was no difference between them in this task--suggesting that this deficit was not related to the fact that letters ("patterns," to them) were used as stimuli.

Furthermore, the possiblity that left hemisphere damage may disrupt the ease of performing mental rotation also makes sense if Kosslyn's (1980, chapter 8) theory is correct. According to the theory, descriptions of shapes are used to realign the parts of the shape as they become scrambled during rotation. That is, rotation is posited to be performed by moving a part at a time. Because there is noise in the system, the parts are not moved precisely the same "distance" at any given iteration of the movement operation. Thus, the parts become misaligned. If the misalignment is small enough, a description of the correct shape can be used to realign them. (If the parts are moved at too large a "distance," they will not be able to be realigned; thus, images are transformed gradually, in a series of small increments.) In this case as well, then, the descriptions used in processing might be stored or processed primarily in the left hemisphere. If so, then left-hemisphere damage would be expected to result in some impairment of mental rotation ability.

In contrast to generation and rotation, the theory posits that neither image inspection nor image scanning requires use of stored descriptions. Thus, it is of interest that the decrements in performance for these tasks are less marked when we attempt to factor out general impairments in response speed. That is, when we look at scanning speed (subtracting times from the no-scanning trials from the scanning trials), we do not find a significant difference between J.E. and the controls. When we subtract the overall times in the perceptual baseline task from those in the image maintenance task, we find that left-hemisphere damage does not necessarily lead to a decrement in response time.

The apparent deficit in image maintenance ability per se observed in the first task (i.e., the increased times with longer delays and more complex stimuli) is also of interest, although the theory did not make strong predictions here. That is, we do not yet have a detailed theory for how images are maintained over time. Perhaps verbal or descriptive strategies are used to maintain visual patterns in an image. If so, then our findings may suggest that left-hemisphere damage disrupts such encoding strategies, which become increasingly useful with complex stimuli or stimuli maintained over longer periods in short-term memory.

The present study would be much more interesting if we had more precise data about the locus of damage and if our subjects had more focused lesions. Such subjects would allow us to test directly Farah's (in press) hypothesis that the left angular gyrus area is critically involved in image generation. This hypothesis was formulated after a careful analytic review of the literature on how brain damage affects imagery, and clearly is worth being taken seriously.

Although the present study is admittedly exploratory, the results suggest that this approach, of attempting to decompose cognitive abilities and examine the sub-abilities separately, has promise in the study of brain damage. Furthermore, if cases can be found that show selective dissociations for the separate imagery abilities, this will provide a new and powerful foundation for theorizing about imagery per se.

Footnotes

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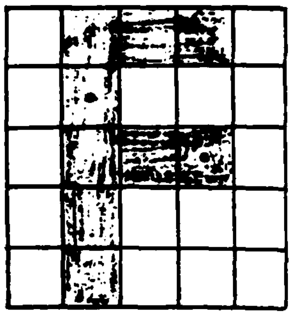
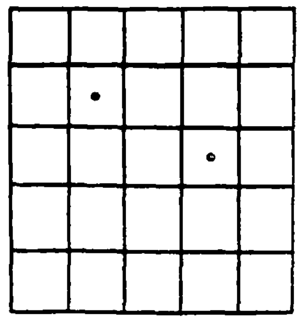
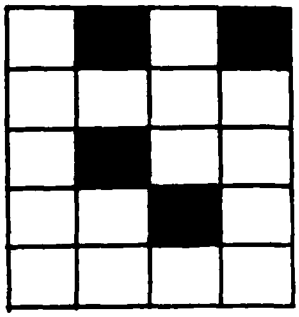
Figures







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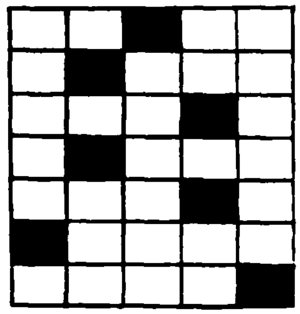
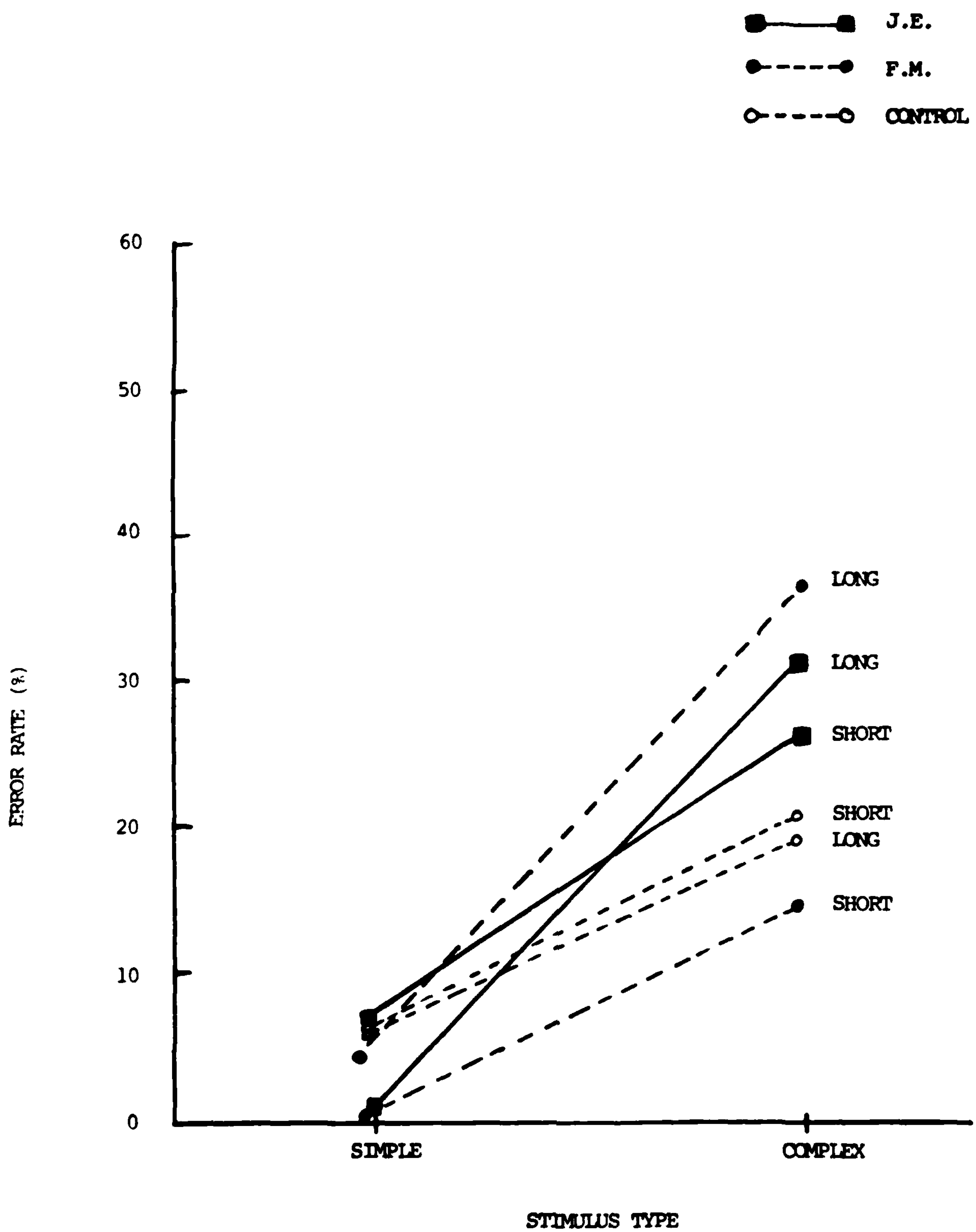


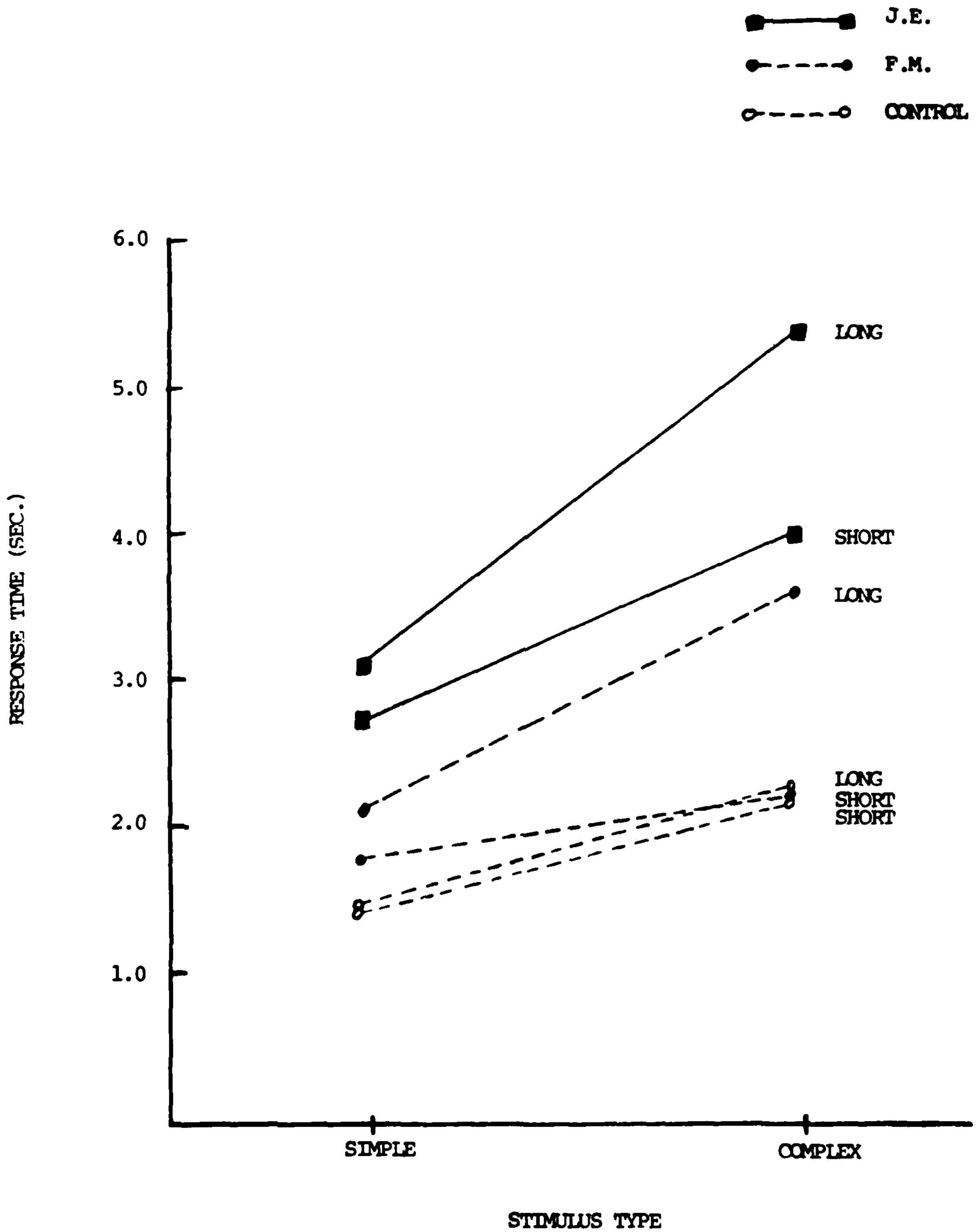
COMPLEX

FIGURE 3

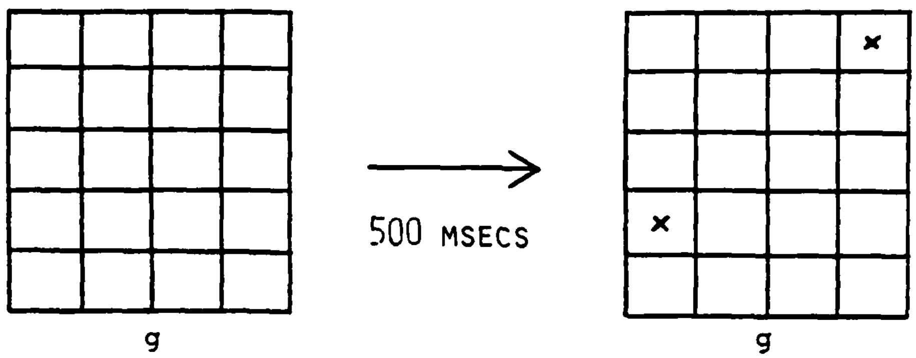


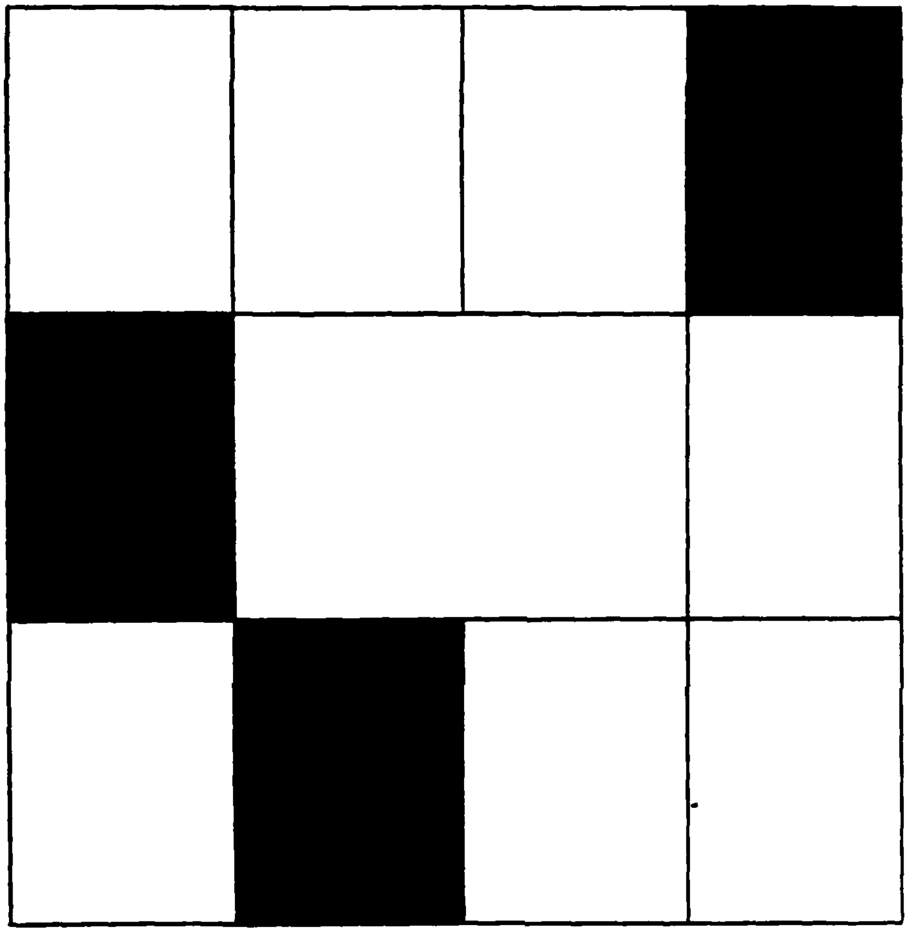
J.E.
F.M.
CONTROL
60
50
40
30
20
10
0
ERROR RATE (%)
LONG
LONG
SHORT
SHORT
LONG
SHORT
SIMPLE
COMPLEX
STIMULUS TYPE

FIGURE 4



J.E.
P.M.
CONTROL
6.0
5.0
4.0
3.0
2.0
1.0
RESPONSE TIME (SEC.)
LONG
SHORT
LONG
LONG
SHORT
SHORT
SIMPLE
COMPLEX
STIMULUS TYPE


500 MSECS
g
g



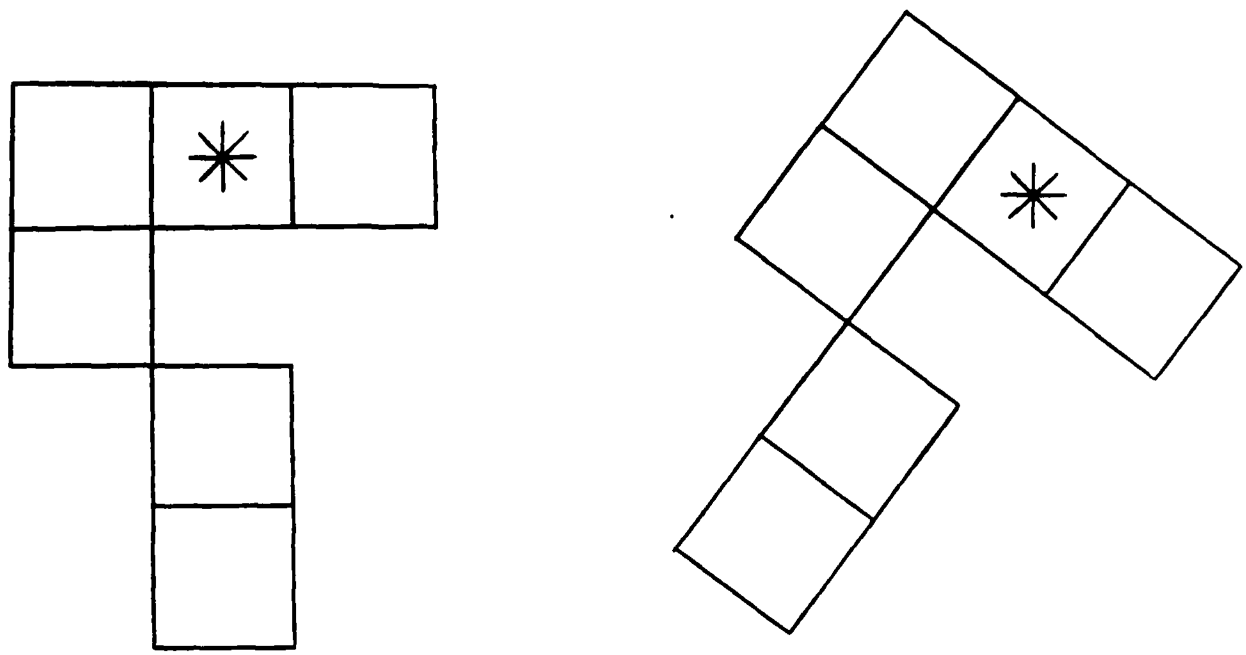


FIGURE 8

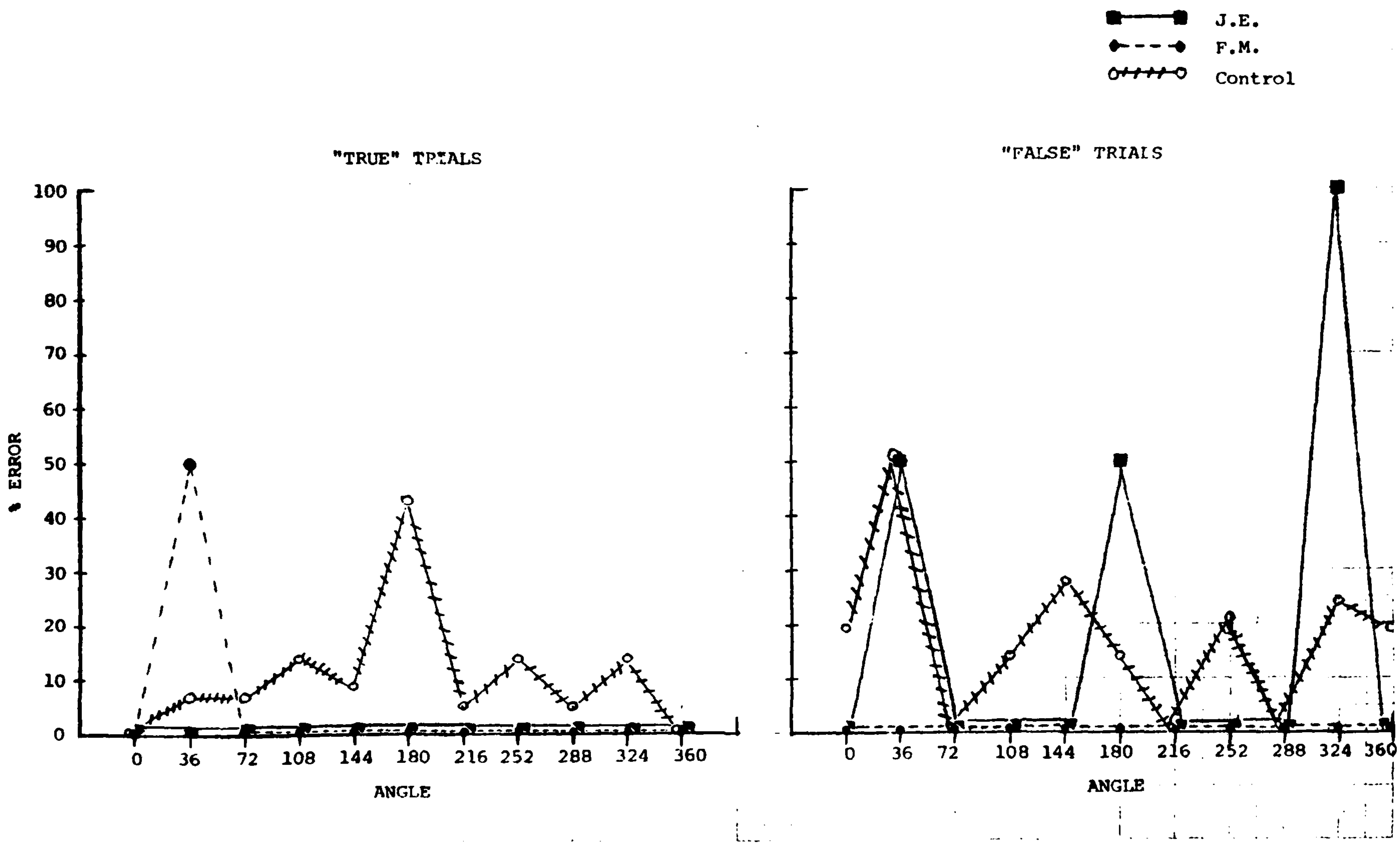
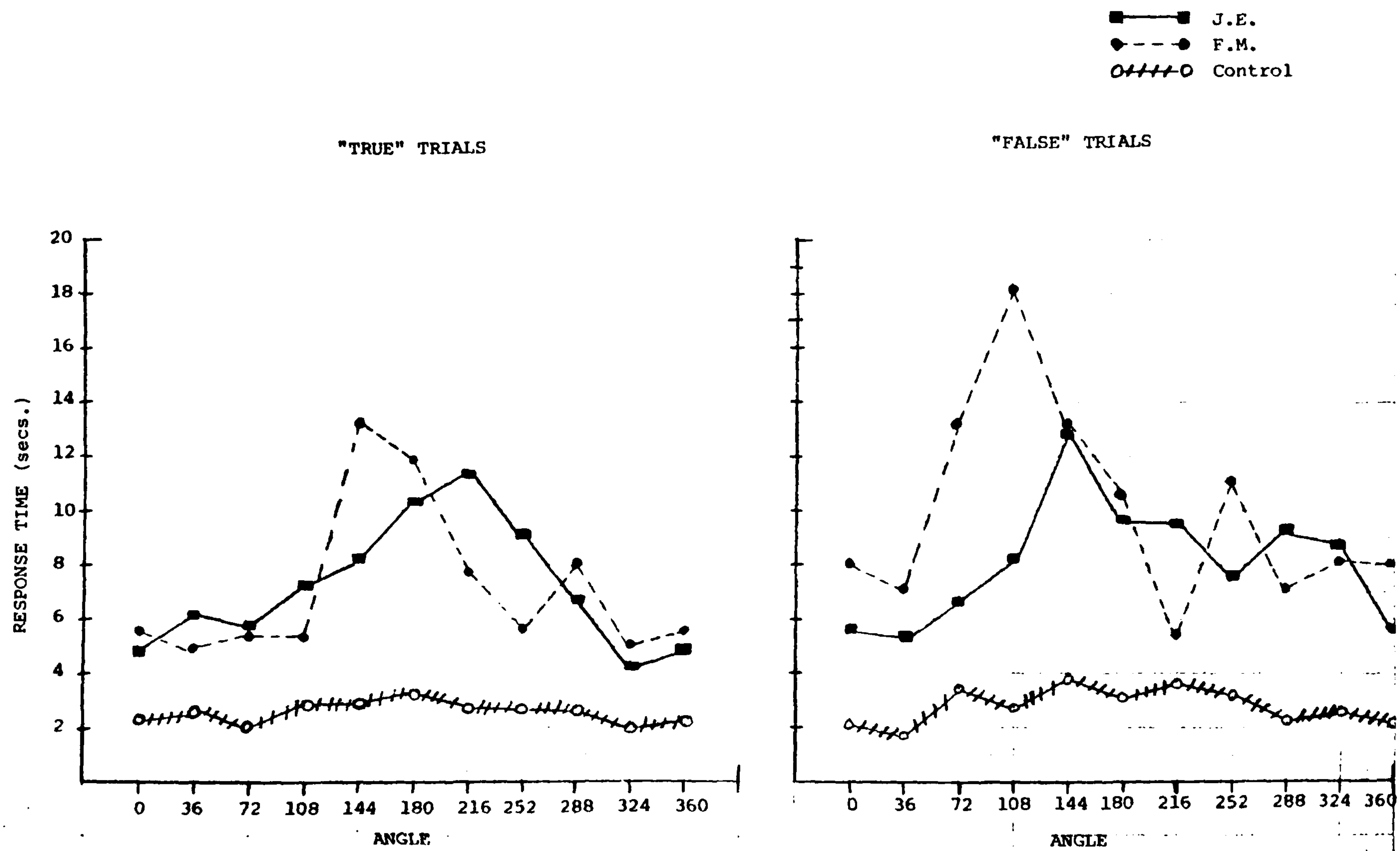

J.E.
F.M.
Control
"TRUE" TRIALS
"FALSE" TRIALS
% ERROR
100
90
80
70
60
50
40
30
20
10
0
0 36 72 108 144 180 216 252 288 324 360
ANGLE
0 36 72 108 144 180 216 252 288 324 360
ANGLE

FIGURE 9


J.E.
F.M.
Control
"TRUE" TRIALS
"FALSE" TRIALS
RESPONSE TIME (secs.)
20
18
16
14
12
10
8
6
4
2
0
36
72
108
144
180
216
252
288
324
360
ANGLE
ANGLE

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